



Edaphic influences on nutritional quality of naturally grown cassava under urban and peri-urban conditions

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Abstract

Cassava (*Manihot esculenta* Crantz) is a potential food security crop widely consumed in tropical and subtropical countries. In Assam, India, wild cassava variants flourish in both rural and urban areas, although there is limited data on their nutritional qualities. This study evaluates the nutritional and anti-nutritional composition of cassava collected from natural landscapes of Kamrup Metro and Kamrup Rural districts of Assam, India, representing as urban and peri-urban areas respectively. Samples were analyzed for nutritional composition (moisture, protein, lipid, ash, starch), essential minerals (Zn, Fe, Mn, Cu), and anti-nutritional factors (phenol, oxalic acid, tannin, and fiber). Significant differences were found in protein, fat, fiber, starch, and phenol amongst the samples. This can be attributed to the influence of edaphic conditions across the sampled sites, as revealed by the results of Pearson's correlation coefficients between soil physico-chemical parameters with nutritional compositions of leaves and tubers of cassava collected from urban and peri-urban areas. The sample from urban area consistently showed elevated levels of starch, lipids, phenols, tannins, oxalates, and fiber, which are the biomarkers commonly associated with stress-response physiology in plants. These findings have significant implications for crop improvement, urban agro-ecology, and climate-resilient food systems.

Keywords Anti · Nutrient, · Climate Resilience · Edaphic condition · *Manihot esculenta* Crantz. · Micronutrients

Highlights

- Nutritional dynamics of wild cassava from urban and peri-urban areas were analysed;
- Nutrients and anti-nutrients of cassava significantly varied in two soil conditions;
- Edaphic factors were statistically correlated with nutrient parameters of cassava;
- Samples from urban area showed elevated levels of stress-adaptive marker compounds;
- Urban samples indicated more resilience with higher micronutrients and antioxidants.

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1 Introduction

Cassava [*Manihot esculenta* Crantz; (Family: Euphorbiaceae)], often known as Tapioca, provides food security for millions of people, particularly in underdeveloped nations. It is an alternative source of energy to address the growing demands of an increasing population. This crop has the potential to increase food production per unit area, tolerate biotic and abiotic challenges, and adapt to drought and marginal areas (Devi et al. 2022). Cassava is farmed on an area of 18.51 million hectares worldwide, yielding 202.65 million tons at a production rate of 10.95 t/ha (FAO 2005). In India, the crop has been cultivated for more than 100 years. In the North-eastern states of India, namely Assam and Meghalaya, around 6,300 hectares of land are under cassava cultivation (Edison et al. 2006). Although cassava has historically been grown for food and industry, it can also be found in various environments in wild or semi-wild forms. In Assam, India, besides farm-grown cassava, wild cassava grows luxuriously in the foothills and plains, particularly in the Kamrup District, which encompasses both urban and rural ecological zones. These wild populations thrive in marginal soils and

uncultivated lands, without human intervention, indicating their hardiness and ecological adaptability.

In Assam, cassava is cultivated not only as a food crop but also for its utility in sericulture. The starchy tubers are consumed by local communities, while the nutrient-rich leaves serve as an important feed source for the eri silk-worm (*Samia ricini*), supporting dual-purpose utilization (Sakthivel 2014). Cassava farmers have the potential to allocate a portion of their cultivation for eri silkworm rearing, thereby generating additional income without compromising the primary yield of tubers, which remains their main economic output. The nutritional quality of cassava leaves, determined by parameters such as moisture content, total protein, total sugars, and total mineral levels, plays a crucial role in influencing the growth and economic traits of the silkworm crop (Mossie et al. 2024). While naturally growing cassava is widely available in Assam, its utilization is minimal due to a lack of awareness about its nutritional potential and concerns regarding its safety. Unlike cultivated varieties, naturally grown cassava may differ significantly in both beneficial nutrients and harmful anti-nutrients. Evaluating its nutritional profile is crucial for identifying its potential as a supplementary or emergency food source in rural and tribal communities, supporting conservation and domestication efforts for nutrient-rich, low-toxic wild genotypes, and contributing to food security strategies in ecologically diverse and economically constrained regions of Northeast India.

Naturally growing cassava in wild conditions, though genetically similar to its cultivated counterparts, remains largely underutilized despite its abundant growth in the foothills and plains of Assam. In the Kamrup district—comprising both urban and peri-urban zones, wild cassava grows luxuriantly in uncultivated lands, roadsides, forest fringes, and hilly slopes. These natural stands of cassava represent a resilient food resource, particularly in remote and economically marginalized areas where food availability can be seasonal or insecure. Evaluating the nutritional composition of these naturally growing cassava may serve as a supplementary food source for low-income or food-insecure communities. Understanding its anti-nutrient composition is crucial to integrate it safely into local diets. Wild variants may possess unique nutritional properties, such as higher mineral content or fiber levels, compared to cultivated varieties, making them valuable for dietary diversification. There are considerable differences in edaphic and environmental dynamics in between urban and peri-urban areas which affect the plant growth, yield as well as nutritional constituents of yields, both in agricultural and wild conditions (Lei et al. 2025). In the present investigation, Kamrup District of Assam was selected as the study area because of its unique urban-peri-urban gradient, which provides a natural environment for comparing cassava growing under various anthropogenic and ecological stresses. Kamrup Metro represents

a typical urban landscape, characterized by high population density, infrastructure development, and environmental stressors. In this setting, cassava that grows naturally is frequently exposed to marginal soils and unfavorable growing conditions, which could affect its nutritional and biochemical composition. On the other hand, Kamrup (rural), which serves as a peri-urban zone, is a transitional area with relatively better soil conditions and vegetation cover while still experiencing moderate human intervention. Therefore, cassava growing in these areas can provide information about how semi-managed environments impact both nutritional and anti-nutritional characteristics.

The nutritional and anti-nutritional composition of these naturally growing cassavas may be influenced by varying levels of environmental stress, soil conditions, and anthropogenic activities across urban and peri-urban landscapes, which justifies the necessity of the present investigation. In addition to accessing their potential for use in human and animal nutrition, an analysis of their biochemical characteristics will provide insight into how cassava adapts to unconventional growing conditions.

2 Materials and methods

2.1 Study area

The study was conducted in five selected sites across two contrasting landscapes in Kamrup district of Assam, India- the Lankeshwar region of Kamrup Metropolitan district, which is classified as an urban area, and four villages in Boko town, which is classified as a peri-urban area in Kamrup Rural district. These sites were strategically chosen to represent the urban–peri-urban gradient, enabling the assessment of how varying levels of urbanization and environmental stress influence the nutritional and anti-nutritional composition of naturally growing cassava. Boko, located in the peri-urban periphery of Kamrup Rural, offers semi-managed green spaces and transitional agricultural activity influenced by surrounding urban growth. The four different villages of Boko from which samples were collected are, namely, Langkona [25.97239N, 91.34673E] (S1), Korebari [25.97508N, 91.32951E] (S2), Bamunigaon [25.99161N, 91.25782E] (S3), and Golakanti [25.97234N, 91.34674E] (S4). The samples were mainly collected from hilly, remote areas. The fifth sampling site (S5), Lankeshwar [26.14429 N, 91.64742 E], is situated about 2–3 km west of Jalukbari, Guwahati, adjacent to the NH-37 highway, exemplifies a fully urbanized environment, marked by higher population density, built infrastructure, and more intense anthropogenic pressures.

2.2 Determination of soil physico-chemical characteristics

Three replicates of soil samples were collected in clean polypropylene bags from a depth of 10–15 cm by digging the soil in a V-shape with the help of a spade. The soil samples were then air-dried by spreading them on clean sheets of paper after breaking the large lumps, and finally, they were sieved through 2 mm sieves for further laboratory analyses.

The pH and electrical conductivity (EC) values were measured using a digital pH and conductivity meter, respectively. The Walkley and Black titration method was used to determine the total organic carbon (OC) content of the soil samples (Jackson 1958). The nitrogen (N) content was determined using the micro-Kjeldahl method (Jackson 1958). The total sodium (Na) and potassium (K) contents in the samples were measured in a flame photometer (APHA 1998). The stannous chloride method was used for the spectrophotometric determination of the available phosphorus (P) (APHA 1998). The available iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) in the soil were determined using a flame atomic absorption spectrophotometer (Kumar and Shiddamallayya 2019).

2.3 Plant Sample collection

Fresh cassava semi-tender leaves and tubers were harvested from the selected sites during the peak harvest season (February–March) to ensure optimal nutritional quality. To prevent contamination, the samples were packaged in sterile plastic containers with labels and were immediately transported to the laboratory and stored in the refrigerator to maintain freshness and prevent spoilage.

$$\% \text{ of lipid} = \frac{\text{Final weight of the round bottom flask} - \text{initial weight of the flask}}{\text{Weight of substance taken (g)}} \times 100 \quad (4)$$

The ash content was estimated after moisture, and all organic constituents were burned at 550°C by using the Eq. 5 (AOAC 1970).

$$\% \text{ of ash} = \frac{\text{weight of the crucible with ash} - \text{initial weight of the crucible}}{\text{Weight of substance taken (g)}} \times 100 \quad (5)$$

2.4 Sample preparation

Fresh cassava samples were subjected to shade drying over several days to achieve complete moisture removal. The dried samples were subsequently ground into a fine powder using a mechanical grinder. The resulting powdered materials were stored in sterile, airtight packets under controlled conditions until further analyses.

2.5 Determination of nutritional composition

Proximate analyses of the samples were determined through standard protocols as per the Association of Official Analytical Chemists (AOAC 1970). Accordingly, the moisture content of the sample was determined by oven-drying 1 g of fresh sample at 105°C till the weight is constant by using the following equation (Eq. 1).

$$\% \text{ moisture} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100 \quad (1)$$

The total nitrogen content of the plant samples was assessed by the Kjeldahl method (AOAC 1970) using Pelican Kelplus equipment (Eq. 2).

$$N\% = \frac{14.01 \times (\text{mL of 0.1N H}_2\text{SO}_4 \text{ used} - \text{blank}) \times 0.1 \times 100}{\text{weight of dried sample} \times 1000} \quad (2)$$

Crude protein was calculated by using Eq. 3, by multiplying total nitrogen percentage by protein factor i.e. 6.25, as reported previously (AOAC 1970).

$$\text{Crude Protein (CP) \%} = \text{Total Nitrogen \%} \times 6.25 \quad (3)$$

Lipid was determined from an oven-dried sample using a Soxhlet extraction apparatus (AOAC 1970) and expressed in percentage on dry weight basis using the following equation (Eq. 4).

Starch estimation was done using the Anthrone method with slight modification (Sadasivam and Manickam 2018).

2.6 Determination of antinutritional contents

Phenol content estimation was carried out by the Folin-Ciocalteu method (Ainsworth and Gillespie 2007). The method involves the reduction of the Folin-Ciocalteu

reagent (FCR) in the presence of phenolics, which leads to a blue-colored reduced product. Oxalic acid estimation was done by the KMnO_4 oxidation method (Naik et al. 2014). Tannin content was determined by the Folin-Ciocalteu method following the methodology of (Govindappa et al. 2011). Fiber content was estimated from fat free sample of dried leaves and tubers both as per method suggested by Fibre content was determined by using following formula (Eq. 6) (AOAC 1970).

$$\% \text{ of crude fiber} = \frac{\text{Weight of crucible with dry residue} - \text{weight of crucible with ash}}{\text{Weight of substance taken (g)}} \times 100 \quad (6)$$

2.7 Determination of mineral nutrients

The dried samples were digested in the muffle furnace, and the ash was dissolved in a 10% nitric acid solution. The dissolved sample was transferred to a 250 mL volumetric flask, and the volume was made up with distilled water and then filtered. The filtrate was used for the further determination of mineral nutrients, including iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu), using flame Atomic Absorption Spectroscopy (AAS) (Kumar and Shiddamallayya 2019).

2.8 Data analysis

Values reported here are means of three replicates with standard deviations ($\pm$). Data were analyzed statistically by analysis of variance (ANOVA) using SPSS software at $p < 0.05$ (Gomez and Gomez 1984). Values reported here are means of three replicates. Data were tested for significant levels at $P = 0.05$ using one-way ANOVA. Pearson Coefficient Correlation analysis was carried out in MS-Excel. Graphical works were carried out using Origin software 8.0.

3 Results and Discussion

3.1 Physico-chemical properties of soil

The soils fall within the slightly acidic to neutral range, which is generally considered favourable for plant growth. S2 (7.19) is closest to neutral, while S4 (6.3) is the most acidic. EC values are low at all sites and range from 0.123 (S4) to 0.167 mS/cm (S1). However, all sites have moderate to high organic matter, important for soil fertility and structure. Sample S3 showed the highest (1.9%) OC, while S2 has the lowest (1.19%). Higher OC in S3 indicates good microbial activity and nutrient-holding capacity, while the lowest OC in S2 may affect its water retention and fertility despite presence of high nutrients, as per previous report (Billings et al. 2021). The Na content across the sampling sites ranged from 17.4 ppm (S2) to 35.73 ppm (S5). The percentage of N varied from 0.02 in S5 to 0.09 in S2. Again, S2 showed better phosphorus availability (38.1 ppm), as compared to others. The range of K in the sampling sites varied from 43.76 ppm in S4 to 71.3 ppm in S5 (Table 1). The highest nitrogen content in S2 has potential to support vigorous vegetation growth, while the lowest N content in

Table 1 Physico-chemical properties of soil collected from five different locations

Sampling sites	Soil parameters						
	pH	EC (mS/cm)	OC (%)	Na (ppm)	N (%)	P (ppm)	K (ppm)
S1	6.54 $\pm$ 0.003 ^a	0.167 $\pm$ 0.001 ^a	1.77 $\pm$ 0.012 ^a	31.56 $\pm$ 2.018 ^a	0.05 $\pm$ 0.001 ^a	35.7 $\pm$ 3.089 ^a	52.46 $\pm$ 4.103 ^a
S2	7.19 $\pm$ 0.023 ^b	0.143 $\pm$ 0.001 ^b	1.19 $\pm$ 0.09 ^b	17.4 $\pm$ 1.008 ^b	0.09 $\pm$ 0.001 ^b	38.1 $\pm$ 2.057 ^b	55.3 $\pm$ 3.009 ^b
S3	6.68 $\pm$ 0.004 ^c	0.14 $\pm$ 0.002 ^b	1.9 $\pm$ 0.1 ^c	25.53 $\pm$ 2.037 ^c	0.05 $\pm$ 0.003 ^a	30.01 $\pm$ 2.002 ^c	56.66 $\pm$ 2.078 ^c
S4	6.3 $\pm$ 0.001 ^d	0.123 $\pm$ 0.001 ^c	1.3 $\pm$ 0.006 ^d	28.53 $\pm$ 2.016 ^d	0.07 $\pm$ 0.004 ^c	37.02 $\pm$ 4.127 ^d	43.76 $\pm$ 1.056 ^d
S5	6.83 $\pm$ 0.018 ^e	0.163 $\pm$ 0.004 ^d	1.5 $\pm$ 0.010 ^e	35.73 $\pm$ 3.002 ^e	0.02 $\pm$ 0.000 ^d	28.6 $\pm$ 1.987 ^e	71.3 $\pm$ 5.036 ^e

$n=3$; error bars indicate SD. Dissimilar letters in the same column in each parameter indicate statistically significant differences ($p < 0.05$)

EC– Electrical conductivity, OC–Organic carbon, ppm– parts per million, Na–Sodium, N– Nitrogen, P– Phosphorous, K– Potassium, S1– Langkona, S2– Korebari, S3– Bamunigaon, S4– Golakanti, S5– Lankeshwar, SD– Standard deviation

Table 2 Nutritional composition of cassava leaves collected from five different sites

Samples	Moisture (%)	Nitrogen (%)	Protein (%)	Lipid (%)	Ash (%)	Starch(μ g/mg)
S1	32.3 $\pm$ 1.33 ^a	4.97 $\pm$ 0.82 ^a	31.10 $\pm$ 5.185 ^a	1.4 $\pm$ 0.003 ^a	6.2 $\pm$ 0.50 ^a	287.9 $\pm$ 37.58 ^a
S2	26.5 $\pm$ 0.99 ^b	5.28 $\pm$ 0.72 ^b	33.04 $\pm$ 4.527 ^b	1.6 $\pm$ 0.002 ^b	8.7 $\pm$ 1.01 ^b	235.8 $\pm$ 36.74 ^b
S3	31.5 $\pm$ 2.01 ^c	5.45 $\pm$ 0.72 ^c	34.02 $\pm$ 2.593 ^c	4.2 $\pm$ 0.01 ^c	8.2 $\pm$ 1.50 ^c	309 $\pm$ 26.08 ^c
S4	29.5 $\pm$ 0.25 ^d	4.82 $\pm$ 0.72 ^d	30.13 $\pm$ 4.537 ^d	1.7 $\pm$ 0.05 ^b	8 $\pm$ 0.99 ^d	260.8 $\pm$ 26.05 ^d
S5	36.3 $\pm$ 1.33 ^e	4.82 $\pm$ 0.05 ^d	30.13 $\pm$ 3.242 ^d	6.2 $\pm$ 0.120 ^d	5.8 $\pm$ 0.95 ^e	323.4 $\pm$ 35.21 ^c

$n=3$; error bars indicate SD. Dissimilar letters in the same column in each parameter indicate statistically significant differences ($p<0.05$)

S1– Langkona, **S2**– Korebari, **S3**– Bamunigaon, **S4**– Golakanti, **S5**– Lankeshwar, **SD**– Standard deviation

Table 3 Nutritional composition of cassava tubers collected from five different sites

Samples	Moisture (%)	Nitrogen (%)	Protein (%)	Lipid (%)	Ash (%)	Starch (μ g/mg) (f.w.)
S1	92.01 $\pm$ 2.05 ^a	0.98 $\pm$ 0.002 ^a	6.13 $\pm$ 0.01 ^a	0.023 $\pm$ 0.001 ^a	0.91 $\pm$ 0.003 ^a	310.53 $\pm$ 40.01 ^a
S2	87.66 $\pm$ 1.99 ^b	1.09 $\pm$ 0.01 ^b	6.81 $\pm$ 0.06 ^b	0.09 $\pm$ 0.013 ^b	0.95 $\pm$ 0.01 ^b	240.35 $\pm$ 17.8 ^b
S3	85.12 $\pm$ 2.02 ^c	0.97 $\pm$ 0.003 ^a	6.06 $\pm$ 0.02 ^a	0.24 $\pm$ 0.002 ^c	0.87 $\pm$ 0.010 ^c	356.74 $\pm$ 30.25 ^c
S4	82.12 $\pm$ 1.50 ^d	1.04 $\pm$ 0.2 ^c	6.50 $\pm$ 1.25 ^c	0.08 $\pm$ 0.003 ^b	1.23 $\pm$ 0.002 ^d	274.00 $\pm$ 26.7 ^d
S5	93.3 $\pm$ 0.95 ^e	0.95 $\pm$ 0.003 ^d	5.94 $\pm$ 0.02 ^d	1.09 $\pm$ 0.01 ^d	0.24 $\pm$ 0.005 ^e	399.66 $\pm$ 39.09 ^e

$n=3$; error bars indicate SD. Dissimilar letters in the same column in each parameter indicate statistically significant differences ($p<0.05$)

S1– Langkona, **S2**– Korebari, **S3**– Bamunigaon, **S4**– Golakanti, **S5**– Lankeshwar, **SD**– Standard deviation

S5 (urban site), indicates need for nitrogen supplementation. Low N and high Na and K in S5 indicate an essential nutrient imbalance in urban soil under study (Edison et al. 2006).

3.2 Nutritional composition

In the leaves, the moisture content ranged from 26.5 $\pm$ 0.99% to 36.3 $\pm$ 1.33%, with the lowest value observed from S2 and the highest value from S5 (Table 2). On the other hand, in case of tubers, the highest moisture content was observed in S5 (93.3 $\pm$ 0.95%) while the lowest was in S4 (82.12 $\pm$ 1.50%). The moisture content of the tuber ranging from 82 to 93%, is consistent with the findings reported by (Wang 2020). Throughout the study, the moisture content in the tuber was found to be much higher than in the leaves (Table 3). This observation is consistent with the physiological role of tubers as storage organs. The elevated moisture content in tubers contribute to higher perishability and underscores the need for proper post-harvest drying and storage methods to prevent spoilage and microbial growth (Nainggolan et al. 2024).

The crude protein content ranged from 30.13 $\pm$ 3.242% to 34.02 $\pm$ 2.593% in leaves, with the highest observed in S4 (Table 2). No significant differences in leaf crude protein content were observed in S4 and S5. Reports previously indicated that cassava leaves contain between 1 to 10 g of protein per 100 g (Salvador et al. 2014). In contrast, Ravindran and Ravindran (1988) reported that young

cassava leaves can have a protein content of 38.1% on a dry-weight basis. Substantially high protein content, ranging from 30 to 34% across all leaf samples, confirms that cassava leaves from selected wild accessions, are an excellent source of plant protein, which has direct implications for eri silkworm rearing as protein plays a vital role in larval growth, cocoon formation, and silk yield in eri silkworms (Saud et al. 2016). Similarly, in the tuber, the lowest crude protein (5.94 $\pm$ 0.019%) was observed in S5 and the highest (6.81 $\pm$ 0.06%) in S2 (Table 3). Protein across tuber samples was low but consistent (5.94–6.81%), which is typical for cassava tuber, commonly reported at 0.3–3.5% of fresh weight and 3–6% of dry weight (Salvador et al. 2014).

Lipid content in leaves was found to be the highest (6.2 $\pm$ 0.120%) in S5 and the lowest (1.4 $\pm$ 0.003%) in S1 (Table 2). While in tubers, the lowest value (0.023 $\pm$ 0.001%) was recorded in S1 and the highest (1.09 $\pm$ 0.01%) in S5 (Table 3). Lipid was relatively consistent in most leaf samples (~ 1.4–1.7%), except notably high in S3 and S5 (4.2% and 6.2%, respectively). This variation supports previous findings that the lipid content of cassava leaves varies greatly (3.5–7.3%) depending on the variety and environmental factors (Scaria et al. 2024; Montagnac et al. 2009). Genetic variations or localized soil fertility that promotes lipid production could be the cause of the higher lipid in S3 and S5. Lipid content in cassava leaves plays a key role in eri silkworm health and productivity. Previous studies show positive correlations

between lipid content in leaves and key eri performance traits, including larval weight, cocoon and pupal weight, shell weight, fecundity, and hatchability (Sakthivel 2014). As the lipid content of cassava is lower than compared of castor (*Ricinus communis*), the primary host for eri silkworm, thus, screening and selecting cassava varieties with high leaf lipid content may prove to be a strategic and effective approach for enhancing eri silkworm rearing. On the contrary, lipid content was minimal in the tuber (0.02–1.09%), and is consistent with the previous finding reporting a range between 0.1 to 0.3% (Salvador et al. 2014). Interestingly, S5 urban sample, showed a higher lipid content in both leaves and tubers, which might be due to localized soil or cultivar-specific lipid metabolism, or a stress-induced defensive response rather than improved nutritional status. Cassava, when exposed to environmental factors like heat, drought, or pollution, which are prevalent in metropolitan settings, suffers from oxidative stress, generating protective lipid compounds to preserve membrane integrity (Sah and Sofo 2024).

The ash content in the studied leaf samples ranged from $5.8 \pm 0.95\%$ in S5 to $8.7 \pm 1.01\%$ in S2 (Table 2). These

results are within the anticipated range of 4–16% for cassava leaves, reported in the previous studies (Salvador et al. 2014). This demonstrates that cassava leaves collected from different sites in urban and surrounding peri-urban areas of Kamrup district are valuable mineral sources, reinforcing their nutritional importance for animal feed and eri silkworm rearing. Similarly, in tubers, the lowest ash was recorded in S5 ($0.24 \pm 0.005\%$) while the highest ($1.23 \pm 0.002\%$) was in S4 (Table 3). Lower level of ash content in tuber in comparison to leaf aligns with the previous findings (Salvador et al. 2014).

The starch content in leaf, calculated on a fresh weight basis, was found to be in the range of $235.8 \pm 36.74 \mu\text{g}/\text{mg}$ (23.5%) in S2 to $323.4 \pm 35.21 \mu\text{g}/\text{mg}$ (32.3%) in S5 (Table 2). In the tuber, the lowest starch content of $240.35 \pm 17.8 \mu\text{g}/\text{mg}$ (24%) was recorded in S2, while the highest content of $399.66 \pm 39.09 \mu\text{g}/\text{mg}$ (40%) was found in S5 (Table 3). Due to its higher starch content, cassava tuber serves primarily as an energy source in human diet in various parts of the globe. Typically, starch content in the tubers varies between 32–35% on a fresh weight basis and 80–90% on a dry weight basis (Montagnac et al. 2009). Therefore,

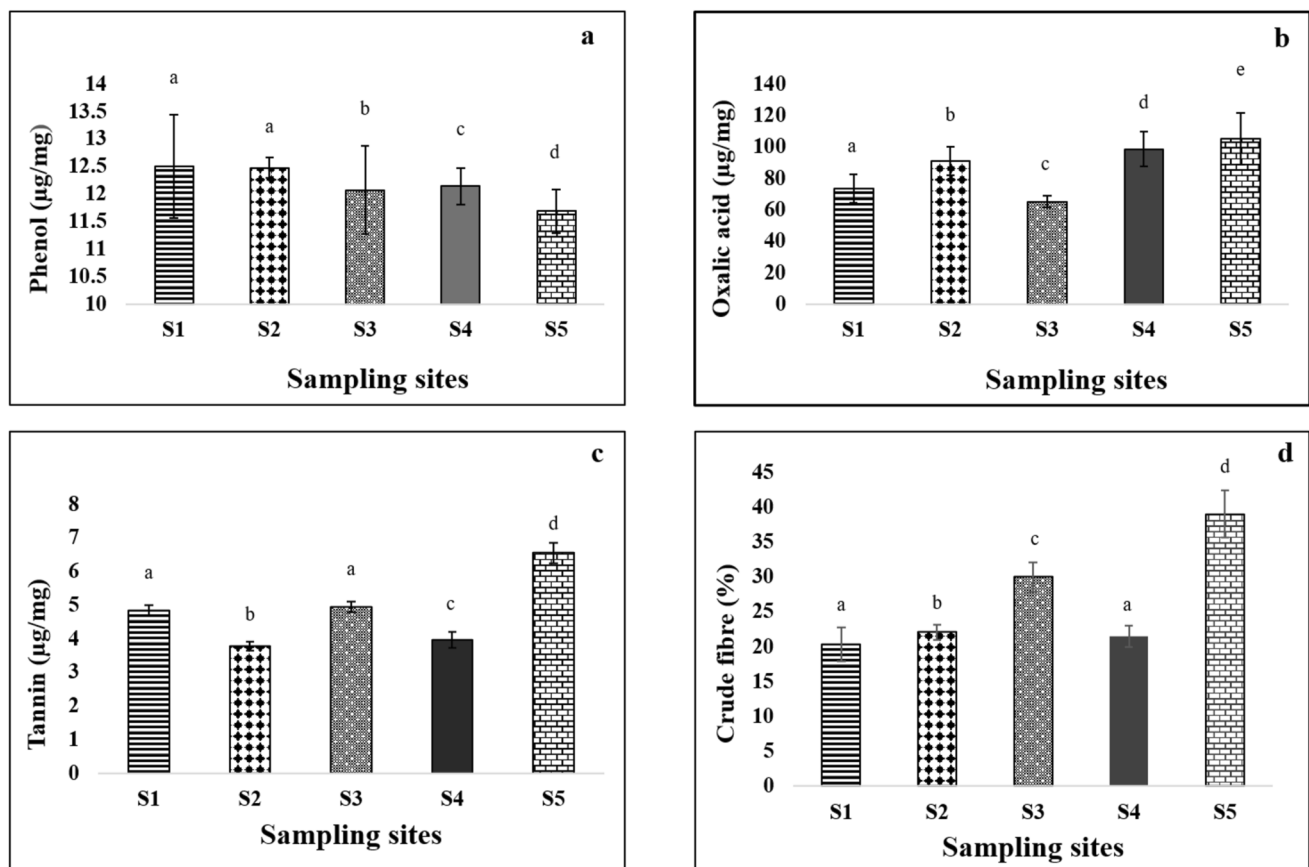


Fig. 1 (a–d) Anti-nutritional contents of cassava leaves collected from different locations [S1- Langkona, S2- Korebari, S3- Bamunigaon, S4- Golakanti, S5- Lankeshwar, SD- Standard deviation]

our results with 24 to 40% starch in tuber also corroborate with the previous findings. For both leaves and tubers, the urban sample (S5) showed the highest starch load as compared to the peri-urban samples (S1-S4), likely reflecting an adaptive stress response. Identifying cassava varieties that combine stress tolerance with high starch accumulation, such as those found in the urban (Kamrup Metro) samples in the present study, is highly valuable for both food security and industrial utility.

3.3 Anti-nutritional contents

Anti-nutritional compounds found in cassava have an impact on the absorption and digestion of nutrients (Salvador et al. 2014), while the quantity depends on the variety and growth stage of cassava (Montagnac et al. 2009). In the present study, the anti-nutrient contents viz. phenol, oxalic, and tannin of cassava leaves and tubers were expressed on a fresh weight basis, while crude fiber was expressed on a dry weight basis. Leaf samples exhibited measurable levels of phenolic compounds with the highest ($12.5 \pm 0.933 \mu\text{g}/\text{mg}$) observed in S1, and the lowest ($11.69 \pm 0.395 \mu\text{g}/\text{mg}$) in S5 (Fig. 1a). No significant differences were observed in

S1 and S2. In tuber, S5 recorded the highest phenol content ($8.99 \pm 2.89 \mu\text{g}/\text{mg}$) as compared to S1-S4 (Fig. 2a). Phenolic compounds play a crucial role when it comes to protecting plants from biotic and abiotic stressors. Because of their antioxidant properties, these substances aid plants in coping with oxidative stress (Rice-Evans et al. 1997), which is particularly important for cassava grown in urban settings that are prone to stress, such as S5.

Oxalic acid in the leaves showed significant differences in all the studied samples, which ranged from $65.2 \pm 3.524 \mu\text{g}/\text{mg}$ in S3 up to $105.06 \pm 16.35 \mu\text{g}/\text{mg}$ in S5 (Fig. 1b). Compared to the leaves, the tuber showed lower values of oxalic acid content, with the highest being $5.8 \pm 0.21 \mu\text{g}/\text{mg}$ at S5 (Fig. 2b). Oxalic acid is one of the common anti-nutrients in cassava, known to interfere with mineral absorption, mainly calcium (Wobeto et al. 2007). However, it can perform a dual role as a chelator and a protective metabolite, particularly under situations of abiotic stress (Wobeto et al. 2007). In the present study, S5 showing the highest oxalic content in both leaves and tubers, indicates that urban stress conditions may induce the accumulation of this anti-nutritional factor.

For tannin content in leaves in the present study, the lowest value ($3.77 \pm 0.133 \mu\text{g}/\text{mg}$) was found in S2, while

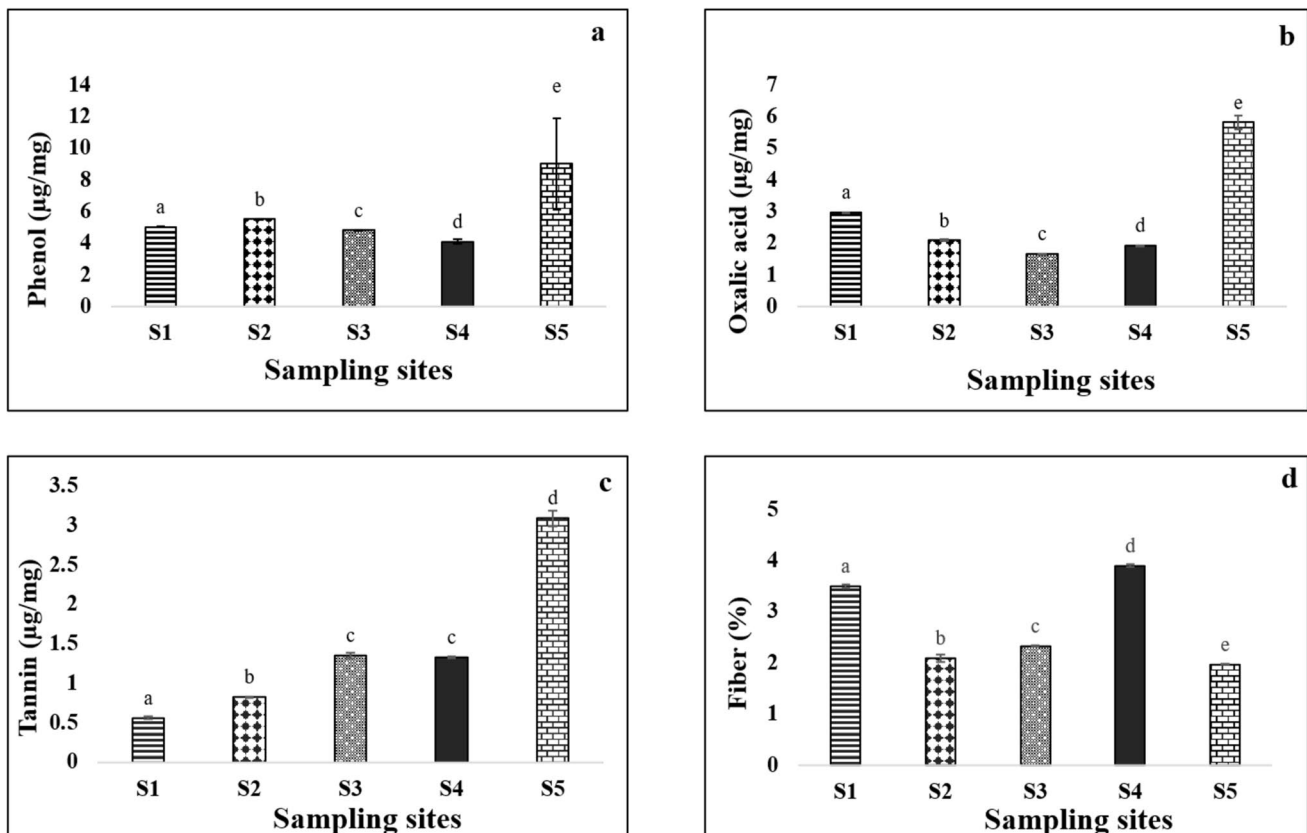


Fig. 2 (a-d) Anti-nutritional contents of cassava tubers collected from different locations [S1- Langkona, S2- Korebari, S3- Bamunigaon, S4- Golakanti, S5- Lankeshwar, SD- Standard deviation]

Table 4 Micronutrient content of cassava leaves and tubers collected from 5 different sites

Sampling sites	Micronutrients (mg/kg)							
	Fe		Cu		Mn		Zn	
	Leaves	Tuber	Leaves	Tuber	Leaves	Tuber	Leaves	Tuber
S1	143.3±28.03	16.3±0.007	22.0±0.02	18.00±0.14	24.3±0.243	8.9±0.003	40.5±0.004	17.7±0.004
S2	201±18.25	24.06±0.05	27.7±0.13	7.1±0.007	50.8±0.45	10.06±0.08	45.5±0.005	11.5±0.028
S3	83.9±20.33	15±16.3	17.8±0.04	2.25±0.05	73.3±0.021	11.8±0.004	56.1±0.01	11.8±0.004
S4	81.7±14.002	19.1±2.60	17.6±0.019	2.99±0.05	109±18.99	12.7±0.048	47.7±0.008	12.7±0.048
S5	194±24.33	33.3±5.51	11.9±0.07	4.1±0.02	156±14.01	17.2±0.021	75.8±0.054	27.2±0.021

Fe– Iron, **Cu**– Copper, **Mn**– Manganese, **Zn**– Zinc, **S1**– Langkona, **S2**– Korebari, **S3**– Bamunigaon, **S4**– Golakanti, **S5**– Lankeshwar

Table 5. Pearson correlation coefficients (PCC) of soil parameters and cassava leaf nutritional compositions across five sampling sites

	pH	EC	OC	Na	N	P	K	Mois ture	Nitro gen	Prote in	Lipid	Ash	Sta rch
pH	1												
EC	0.277 633	1											
OC	- 0.309 9	0.396 266	1										
Na	- 0.534 32	0.486 638	0.383 173	1									
N	0.214 986	0.599 54	0.551 81	0.885 21	1								
P	- 0.015 5	- 0.365 94	- 0.577 57	- 0.571 45	0.869 855	1							
K	0.535 315	0.649 27	0.165 491	0.380 72	0.700 95	0.765 81	1						
Mois ture	- 0.237 53	- 0.618 592	- 0.506 838	- 0.916 361	- 0.995 96	- 0.824 98	0.682 993	1					
Nitro gen	0.472 708	- 0.170 79	- 0.321 261	- 0.711 19	- 0.369 49	- 0.047 34	- 0.027 19	- 0.445 65	1				
Prote in	0.481 332	- 0.165 35	- 0.313 241	- 0.718 74	- 0.378 943	- 0.034 78	- 0.029 77	0.454 28	0.999 845	1			
Lipid	0.171 001	- 0.312 397	- 0.289 579	- 0.517 75	- 0.809 69	- 0.947 73	- 0.857 833	0.775 199	0.063 52	0.074 56	1		
Ash	0.212 594	- 0.802 97	- 0.335 77	- 0.898 56	- 0.834 845	- 0.474 244	- 0.542 57	0.875 28	0.643 704	0.644 657	0.442 32	1	
Starc h	- 0.218 12	- 0.501 491	- 0.716 813	- 0.768 414	- 0.959 11	- 0.939 68	- 0.651 407	0.931 517	0.125 37	0.137 12	0.823 438	0.67 655	1

EC- Electrical conductivity, OC-Organic carbon, ppm- parts per million, Na-Sodium, N- Nitrogen, P- Phosphorous, K- Potassium

the highest ($6.55 \pm 0.313 \mu\text{g}/\text{mg}$) was in S5 (Fig. 1c). Tannin ranged between $0.56 \pm 0.021 \mu\text{g}/\text{mg}$ (S1) to $3.09 \pm 0.1 \mu\text{g}/\text{mg}$ (S5) in tubers (Fig. 2c). Tannins are naturally occurring polyphenolic compounds known for their role in plants' defence against various environmental stressors (Iqbal and Poor 2025). Their elevated accumulation in both leaves and tubers of urban sample S5 can be attributed to the urban environmental conditions typically characterized by pollution and anthropogenic stress. While beneficial for plant defence, such increases may influence the nutritional and economic value of the crop. Previous studies have reported that tannins hinder the uptake of

non-heme iron and lower the absorption of thiamine, lipid, and protein (Silva and Silva 1999).

For crude fiber content in leaves, no significant differences were observed in S1 ($20.39 \pm 2.24 \mu\text{g}/\text{mg}$) and S4 ($21.52 \pm 1.5 \mu\text{g}/\text{mg}$). The highest value ($39.02 \pm 3.39 \mu\text{g}/\text{mg}$) was found in S5 (Fig. 1d). On the contrary, tubers collected from S1 showed the highest fiber ($3.5 \pm 0.032 \mu\text{g}/\text{mg}$) while S5 showed the lowest ($1.97 \pm 0.006 \mu\text{g}/\text{mg}$) (Fig. 2d). In our study, the fiber content in cassava leaves was found to be highest in sample S5, collected from the Urban site. Dietary fiber plays a crucial structural role in plant tissues and is known to increase under various forms of abiotic stress. Plants

Table 6. Pearson correlation coefficients (PCC) of soil parameters and cassava tuber nutritional compositions across five sampling sites

	pH	EC	OC	Na	N	P	K	Mois ture	Nitro gen	Prote in	Lipid	Ash	Sta rch
pH	1												
EC	0.277 633	1											
OC	- 0.309 9	0.396 266	1										
Na	- 0.534 32	0.486 638	0.383 173	1									
N	0.214 986	0.599 54	0.551 81	0.885 21	1								
P	- 0.015 5	- 0.365 94	- 0.577 57	- 0.571 45	- 0.869 855	1							
K	0.535 315	0.649 27	0.165 491	0.380 72	0.700 95	0.765 81	1						
Mois ture	0.368 489	0.974 5	0.214 053	0.487 712	0.598 65	0.367 01	0.737 471	1					
Nitro gen	0.327 653	0.557 25	0.779 38	0.820 92	0.950 297	0.856 016	0.549 23	0.488 08	1				
Prote in	0.325 689	0.553 4	0.780 61	0.817 66	0.949 667	0.859 21	0.550 33	0.484 21	0.999 97	1			
Lipid	0.224 166	0.424 18	0.017 78	0.598 762	0.786 98	0.784 88	0.891 94	0.553 587	0.582 38	0.583 14	1		
Ash	0.396 18	0.694 6	0.184 9	0.539 12	0.795 398	0.778 196	0.982 59	0.782 26	0.633 172	0.633 263	0.92 957	1	
Starc h	0.110 41	0.492 214	0.607 795	0.743 609	0.962 38	0.970 38	0.746 889	0.485 787	0.939 61	0.941 07	0.79 524	0.79 985	1

EC- Electrical conductivity, OC-Organic carbon, ppm- parts per million, Na-Sodium, N- Nitrogen, P- Phosphorous, K- Potassium

exposed to such stressors tend to strengthen their cell walls as a defensive adaptation, leading to increased fiber biosynthesis (Waqas et al. 2019). From a nutritional aspect, higher fiber content may have both advantages and disadvantages. Although fiber is essential for digestive health in humans and animals, excessive fiber, as in leaves from urban sample S5, if used for feeding eri silkworm, may reduce digestibility and hinder nutrient absorption in eri silkworm (Devi et al. 2021).

3.4 Micronutrient content

Leaf Fe content was the highest in S2 (201 ± 18.25 mg/kg), followed by S5 (194 ± 24.33 mg/kg), while in the tuber, Fe was the highest in S5 (33.3 ± 5.51 mg/kg). Similarly, Cu content in the leaves ranged from 11.9 ± 0.07 mg/kg in S5 to 27.7 ± 0.13 mg/kg in S2 (Table 4). Sample S1 had the highest Cu content in the tuber, 18.00 ± 0.14 mg/kg, while other sites had significantly lower levels of Cu (Table 4). Again, Mn content in the leaves ranged from 24.3 ± 0.243 to 156 ± 14.01 mg/kg, with the highest value at S5. In the tuber, Mn content was much less than in leaves, ranging from 8.9 ± 0.003 to 17.2 ± 0.021 mg/kg. However, Zn in the leaf and tuber was significantly higher in S5 (75.8 ± 0.054 mg/kg) and (27.2 ± 0.021 mg/kg), respectively, as compared to the rest of the samples (Table 4). Micronutrient content (Fe, Cu, Mn, Zn) in samples across five sampling sites (S1–S5) revealed higher micronutrient levels in the leaves as compared to the tubers. The sample collected from the urban site (S5) exhibited elevated values for most nutrients compared to rural sites. This can be attributed to a combination of several environmental factors, such as elevated nutrient deposition from organic pollution and runoff, as well as stress-mediated nutrient retention, elevated plant uptake and tissue concentrations compared to rural sites. As a defensive strategy, plants may limit translocation to growing sinks under stress, retaining more nutrients in their leaves and tubers (Martín-Cardoso and Segundo 2025).

3.5 Correlation analyses

Pearson's correlation coefficients of soil parameters versus studied nutritional parameters of leaf and tuber from five sampling sites were calculated to analyse the positive and negative correlations among the parameters (Table 5, Table 6). The OC in soil showed a strong positive correlation with the moisture and starch content of the leaf ($r=0.506838$ and $r=0.716813$), respectively, while it showed a moderate positive correlation with leaf protein ($r=0.321261$) and lipid ($r=0.289379$). Similarly, the OC in the soil also showed positive correlations with moisture and starch of the tuber ($r=0.214053$ and $r=0.607795$ respectively). Likewise, Na content in soil is strongly positively correlated with leaf starch ($r=0.768414$), lipid ($r=0.51775$), and moisture

($r=0.916361$). In a comparable trend, Na is positively correlated with moisture, lipid, and starch of the tuber also ($r=0.487712$, $r=0.598762$, $r=0.743609$, respectively). However, Na is negatively correlated with protein and ash ($r=-0.71874$, and $r=-0.89856$, respectively) of leaf. Interestingly, N and P in soil are strongly and moderately correlated ($r=0.834845$, and $r=0.474244$, respectively) to ash in the leaf. Nevertheless, K in the soil showed a strong positive correlation with leaf moisture, lipid, and starch ($r=0.682993$, $r=0.857833$, $r=0.651407$, respectively). In a similar trend, K in the soil showed positive correlation with the starch of the tuber ($r=0.746889$) (Table 6). Such correlations of soil physico-chemical parameters with nutritional compositions of leaves and tubers align with several previous reports (Xing et al. 2020; Alotaibi and Abd-Elgawad 2023; Yin et al. 2023; Gedam et al. 2024). These findings reveal the influence of edaphic factors in nutritional variations of cassava collected from urban and peri-urban areas.

4 Conclusions

The present study provides valuable insights into the nutritional and anti-nutritional profiles of wild cassava samples that are naturally growing across urban and peri-urban habitats of the Kamrup Districts in Assam. The nutritional composition of naturally growing cassava samples collected from different urban and peri-urban locations, revealed notable variations in the nutritional compositions, including carbohydrate, protein, fat, moisture, ash, and fiber content. These differences can be attributed to the influence of edaphic conditions across the sampled sites, as revealed by the results of Pearson's correlation coefficients between soil physico-chemical parameters with nutritional compositions of leaves and tubers of cassava collected from urban and peri-urban areas. The findings suggest that naturally growing cassava from urban habitats exhibits adaptive mechanisms through enhanced accumulation of starch, fiber, lipids, and several antioxidant compounds, including phenolics and tannins, which are biomarkers commonly associated with plant responses to environmental stressors such as poor soil quality, pollution, and limited water availability. This differential accumulation suggests that urban cassava varieties might have built-in stress-resilience mechanisms that allow them to survive and even thrive in harsh environments. Considering climate change, where abiotic stress tolerance is becoming more crucial, such robust and nutritionally enhanced genotypes may be excellent choices for upcoming crop improvement initiatives. Additionally, the biochemical diversity of these naturally growing variants highlights their potential for a variety of uses, such as breeding for improved varieties or their incorporation into low-input farming systems in sustainable agriculture. Additionally, these genotypes can be

useful in sericulture, especially for the rearing of eri silk-worms, which depend on lipid-rich foliage, considering the notable lipid content in cassava leaves, especially in urban samples. Further, optimization of leaf quality could contribute to sustainable sericulture in rural and peri-urban areas. Overall, the study highlights the untapped potential of naturally growing cassava in unconventional settings, and supports the idea that urban and peri-urban landscapes can serve as reservoirs of genetic diversity and nutritional resources, contributing to food security, sustainable development, and future-ready crop strategies.

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Author contributions Sajjad Hussain carried out the soil and plant material collection, nutritional and antinutritional analyses of leaf samples on the bench in laboratory as well as respective statistical analyses of data. Barsha Devi undertook nutritional and antinutritional analyses of tuber samples, mineral element analyses of both leaf and tuber samples and soil physico-chemical analyses on the bench as well as did statistical data analyses and drafted the manuscript initially. Mahananda Chutia supervised the overall analyses, and experimental designing, as well as helped in initial draft preparation of the manuscript. Nabanita Bhattacharyya conceived the idea of the study and participated in its design and coordination as well as participated in the data interpretation, and did the overall final compilation. All the authors thoroughly read and commented on the previous drafts of the manuscript and agreed with the final manuscript.

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Declarations

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